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The Combustion of Noble-Fir Trees in the Presence of an Applied Wind Field

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Abstract: Wildland fires that spread into urban areas, termed wildland-urban interface (WUI) fires, are becoming more and more common across multiple locations of the world. An important component in rapid spread of large outdoor fires is the production or generation of new, far smaller combustible fragments from the original fire source referred to as firebrands. Firebrands signifies any hot object in flight that are capable to ignite other fuel types. Firebrands are produced or generated from the combustion of vegetative and structural fuels. Firebrand processes include generation, transport, deposition, and ignition of various fuel types, leading to fire spread processes at distances far removed from the original fire source. The production of firebrands occurs from the combustion dynamics of vegetative and man-made fuel elements, such as homes. In this work, conifer trees (Noble-fir) were used to study the vegetative combustion process under an applied wind field. Two ignition methods were studied: the first employed a special propane burner and the second considered the use of firebrand showers impinging onto the trees. Specifically, temporally resolved mass loss profiles and heat flux profiles, as well as firebrand distributions were determined. Here, some initial findings of associated firebrand production are presented under 3 m/s and compared to experiments performed under no wind conditions. These experiments provide much needed experimental understanding needed to be able model vegetative combustion processes.
Keywords: large outdoor fires; firebrands; wind

1. INTRODUCTION

The large outdoor fire problem is a wide-spread global issue that shows no signs of abating. Perhaps the most well-known type of large outdoor fires are known as wildland fires that spread into developed, urban areas, known as wildland-urban interface (WUI) fires [**1-2**] As an example, the 2018 WUI fires in the US state of California demonstrated the shear destruction that WUI fires are capable of by destroying more than 18,800 structures and resulting in multiple fatalities [**3**]. In 2020, the situation grew even worse, with multiple fires reported all over the Western US. The size of areas burned in 2020 is simply staggering. In California, the August Complex fire itself consumed more than 1 million acres [**4**].

An important component in rapid spread of large outdoor fires is the production or generation of new, far smaller combustible fragments from the original fire source referred to as firebrands. Firebrands signifies any hot object in flight that are capable to ignite other fuel types. Firebrands are produced or generated from the combustion of vegetative and structural fuels. Firebrand processes include generation, transport, deposition, and ignition of various fuel types, leading to fire spread processes at distances far removed from the original fire source.

While it may be surprising to the reader, there has been little in the way of quantification of firebrands from vegetative fuel sources. Manzello and co-workers have recently completed a comprehensive review of firebrand processes [**5**]. To aid in understanding and to properly place this new study in the context of the past literature, some of this past work that has been reviewed has been repeated here for completeness.

In early pioneering work, laboratory experiments to investigate firebrands from actual tree combustion were performed by using Douglas-fir trees 5.2 m in height with a 3 m wide maximum girth by Manzello and co-workers [**6**]. As a first step, no wind was applied, and firebrands were collected by pans filled with water. Trees with 50% moisture content (MC) partially burned with no firebrands produced while the trees with 18% MC were engulfed in flames after only 20 s after ignition, producing numerous firebrands. Firebrands collected from trees with 18% MC had cylindrical shapes with an average size of 4 mm in diameter and a length of 53 mm. In addition, another experimental series was performed with Douglas-fir trees 2.4 m in height with a 1.5 m wide maximum girth. The average size of firebrands was 3 mm in diameter and a length of 40 mm.

In a follow-on study by Manzello *et al*., [**7**], Korean pine was combusted at the Building Research Institute (BRI) Fire Research Wind Tunnel Facility (FRWTF) to investigate the difference in firebrand production from different tree species; no wind was applied. The height was kept constant at 4.0 m, and pans with water were placed around the tree for the firebrand collection. In order to have Korean pine combusted completely with a significant number of firebrands produced, it was found that MC had to be kept below 35% without any wind applied. The burn progressed somewhat sporadically, taking more than 2 min to complete. This was almost double duration for Douglas-fir trees (50–60 s). Firebrands were found to be cylindrical in shape with an average diameter of 5 mm and average length of 34 mm. The total mass of firebrands produced from each tree size was normalized with the mass lost from the tree during the burn as well as initial mass of the tree. While Douglas-fir trees showed a decrease in firebrand production (almost half) with an increase in tree height (almost double), Korean pine trees produced a larger ratio of mass of firebrands compared with Douglas-fir trees. With the ratio of burnable parts (needles and twigs) of Douglas-fir and Korean pine being similar, this reflects the difference of burning behavior between the two species. As mentioned previously, it took more than 2 min for Korean pine to burn completely while Douglas-fir trees burned out completely in 50–60 s for both heights tested. Douglas-fir trees also have a fuller, less open structure than Korean pine. The (HRR) estimated during the experiments in each case showed that, as for similar MC, Douglas- fir burns produced higher HRR than Korean pine. It was assumed that as most of firebrands produced or collected in this series were relatively small, the more intense fire plume from higher HRR Douglas fir burns might have consumed smaller firebrands completely before collection **[7**].

In more recent work, Blunck and co-workers [**8**] have been investigating firebrand combustion from various tree species. The most impressive component of their work is the sheer number of individual trees burned. Yet, none of the experiments were conducted under a controlled wind field, so the results are not a significant advancement to better understand firebrand generation processes in the present of wind [**8**].

In present study, Noble-fir trees were used to study the vegetative combustion process under an applied wind field. Noble-fir was used since it is easy to obtain from tree farms in the Western US and was easily imported to Japan. Two ignition methods were studied: the first employed a special propane burner and the second considered the use of firebrand showers impinging onto the trees. Specifically, temporally resolved mass loss profiles and heat flux profiles, as well as firebrand distributions were determined. Presently, some initial findings of associated firebrand production are presented under 3 m/s and compared to experiments performed under no wind conditions.

2. EXPERIMENTAL DESCRIPTION

A series of experiments were conducted using the wind facility at the National Research Institute of Fire and Disaster (NRIFD). The facility is able to generate a uniform wind profile with a cross section of 2.0 m by 2.0 m. The maximum wind speed possible using this facility is 10 m/s. The experiments made use of Noble-fir tree species, common in the Western US. The trees were imported from the state of Oregon in the USA. The maximum height of all trees was 1.5 m and was intentionally selected. The maximum girth or width varied as recorded for each experiment but was 1.0 m on average.

Upon arriving at NRIFD, the trees were stored in the laboratory to be able to control the MC. Samples of needles were taken on a daily basis, from three different areas of each tree, and oven dried to determine the MC. Similar procedures were used in prior, no wind studies [**6-7**]. A total of 20 trees were used for the experiments.

Each tree was placed on top of a load cell. Care was taken to protect the load cell from the heat generated from the combustion process. The trees were placed on top of gypsum board custom cut and sized to shield the load cells from the combustion process. The load cell was calibrated using a series of known mass samples prior to the experiments. The load cells were used to determine the temporal evolution of mass loss during combustion. In addition, a custom heat flux transducer array was fabricated for the experiments. Due to space considerations, these data are not presented here.,

To collect firebrands, both water pans as well as series of cameras were used to image firebrand production. Water pans were used to be able to directly compare results to legacy studies reviewed above.

A major goal of the present study was to determine an accepted ignition strategy for the trees under wind. As indicated, past experiments made use of no wind conditions to be able to gather basic understanding of the vegetative combustion process. Yet, it is obvious that in actual large outdoor fires, these combustion processes never occur without the present of wind. As a result, a new ignition strategy was needed. The most successful method made use of a 60 cm burner, oriented in a T shape, placed vertically along-side the trees.

Several burner configurations were attempted but this strategy was the most successful to yield sufficient combustion of the trees under wind. It was also observed that is was not possible to ignite the trees under no wind and then apply the wind. Such a strategy has been used by the authors for structural fuels, please see Suzuki and Manzello [**9**]. In the case of vegetative fuels, the subsequent ignition processes are very quick, on the order of tens of seconds, so by the time the wind was applied, nearly the entire tree would be consumed. Therefore, the strategy developed here allowed for ignition in the present of the applied wind field.

In addition to the T-shaped burner ignition methodology, there was interest to see if firebrand showers alone could result in tree ignition and combustion. For those experiments, the reduced-scale firebrand generator was used (see **Figure 1**). A reduced-scale continuous feed firebrand generator was used to generate firebrand showers. The description here closes follows Suzuki and Manzello [**10**] but is repeated here for completeness. This reduced-scale continuous feed firebrand generator consisted of two parts; the main body and continuous feeding component. The feeding part was connected to the main body and had two gates to prevent fire spread. Each gate was opened and closed alternatively. A blower was also connected to the main body and this was needed to loft and control the combustion state of the generated firebrands. The blower speed at the exit was set to 4.0 m/s to generate glowing firebrands. When the blower was set to provide an average velocity below 4.0 m/s, insufficient air was supplied for combustion and this resulted in a great deal of smoke being generated in addition to firebrands. Above 4.0 m/s, smoke production was mitigated but then many firebrands produced were in a state of flaming combustion as opposed to glowing combustion. In these experiments, glowing firebrands were desired, so these were generated. A longer main body was adapted so that only the firebrand generator part was above the stage, so the feeding part was not affected by wind. A conveyor was used to feed wood pieces continuously into the device. For all tests, Japanese Cypress wood chips were used to produce firebrands. These same size wood pieces have been shown to produce firebrands within projected area/mass of burning structures. As indicated, a conveyor was used to feed wood pieces continuously into the device. The conveyor belt was operated at 1.0 cm/s, and wood pieces were put on the conveyor belt at 12.5 cm intervals. The wood feed rate was fixed at 80 g/min, near the upper limit of reduced-scale firebrand generator.

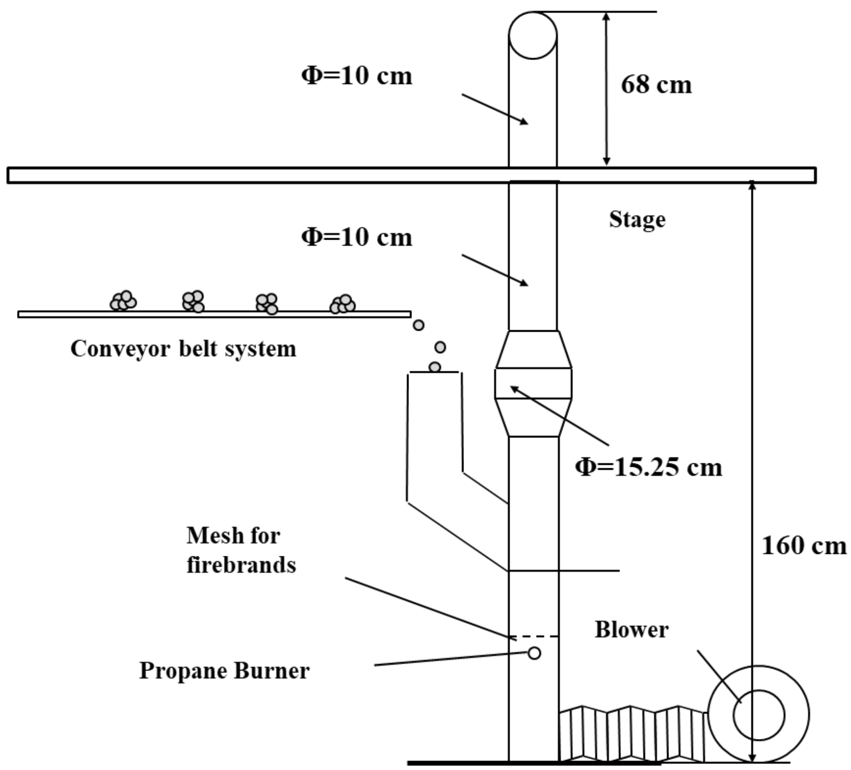

Figure 1 The reduced-scale firebrand generator is shown installed in NRIFD’s wind facility. Wood pieces are continuously feed into the device to generate firebrand showers.

3. RESULTS AND DISCUSSION

Figure 2 displays the temporal evolution of tree ignition and subsequent combustion processes under a 3 m/s wind speed. The total tree height in this experiment was 1.5 m.

Figure 2 The top image shows the combustion process just after burner application and the bottom image shows the extensive firebrand generation processes. In this experiment, was applied wind speed was 3 m/s. The burner was applied for 10 s.

To clearly see the differences in studying the combustion processes under wind, another series of experiments were conducted under no wind. **Figure 3** displays a 1.5 m Noble-fir tree burning under no wind, with a similar MC as the tree in **Figure 2**. As can be seen, in the absence of wind, the buoyant fire plume remains vertical, as opposed to being titled on its axis in the present of wind.

Figure 3 The combustion process just after burner application for a 1.5 m Noble-fir tree. In this experiment, no wind was applied. The differences are apparent in comparison to experiments under an applied wind field (see **Figure 2**). The burner was applied for 10 s.

3.1 Comparison to Ignition from Firebrand Showers

It was also desired to determine if it was possible to ignite trees using firebrand showers. In this case, the reduced scale firebrand generator was used. **Figure 4** displays the temporal evolution of the tree ignition process from firebrand showers at an applied wind speed of 3 m/s.

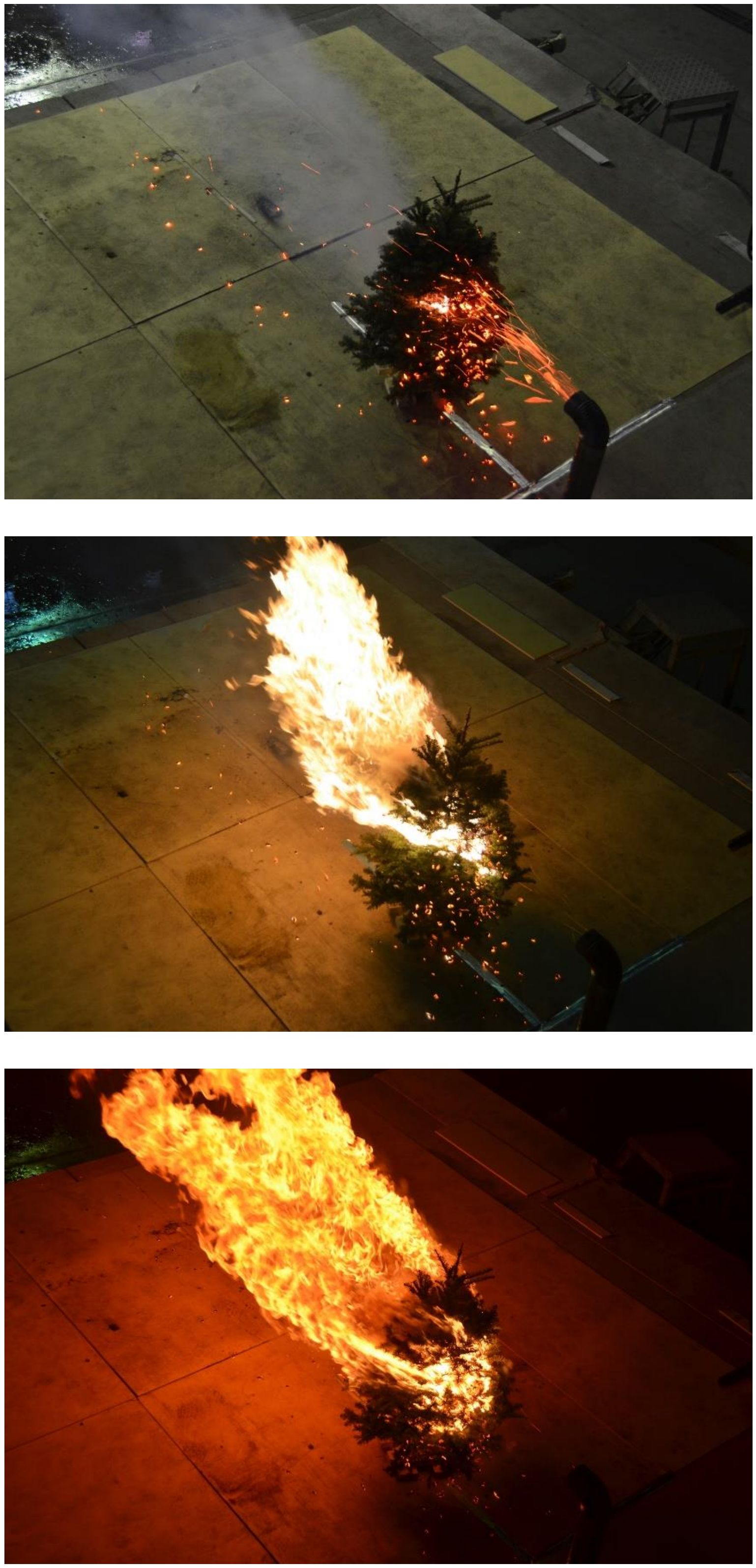

Figure 4 The combustion process of 1.5 m Noble-fir tree after ignition from firebrand showers. In this experiment, a 3 m/s wind was applied, and firebrand showers were selected to be commensurate to burning structures.

4. ASSOCIATED FIREBRAND PROCESSES

In the combustion process of vegetative fuels, pyrolysis of the fuel elements is an important mechanism. In the case of conifer tree combustion, fuel elements consist of needles, bark, and branches. During the combustion of vegetative fuel elements, these pyrolysis reactions result in the generation of gases and vapors and also act to weaken the structural integrity of the original fuel source itself as a result of the mass loss processes.

An interesting approach to model the generation of firebrands from vegetative fuels considered the use of fractal geometry to attempt to describe the various vegetative types [**11**]. In that work, comparisons were made to firebrand collected from Manzello *et al.*, [**6**]; experiments of conifer tree combustion in the absence of wind.

As these combustion processes occur during actual large out fires, the application of aerodynamics forces from the interaction of wind forces imposed by the atmospheric boundary layer to vegetative fuel elements results in the breakage of small elements, that once lofted, become firebrands. **Figure 5** displays some of the collected firebrands from Noble-fir tree combustion, both under wind (3 m/s) as well as without wind application. As may be seen, the application of wind resulted in heavier firebrands being generated. Preliminary analysis of firebrand projected areas in shown in **Figure 6.** Standard uncertainty in projected area (±10%) and mass (±1%).

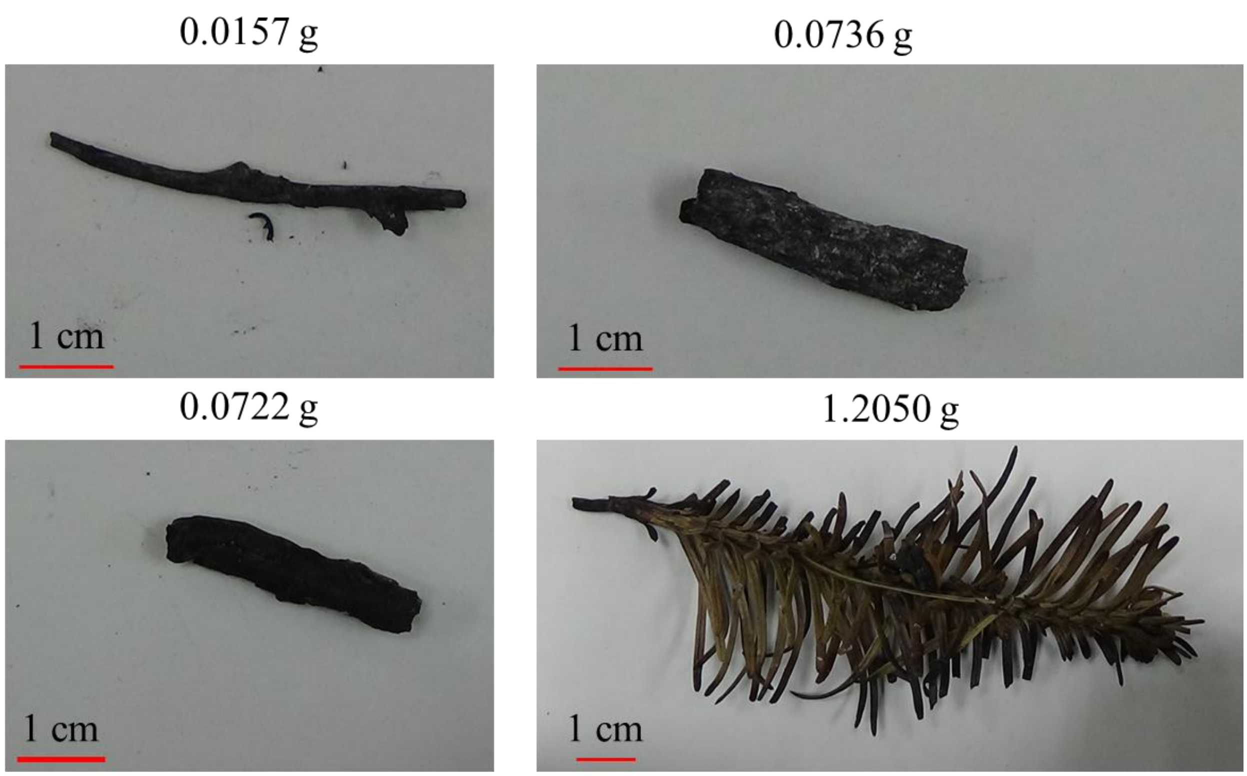

Figure 5 Samples of collected firebrands. The top panel shows firebrands collected from Noble-fir combustion under no wind. The bottom panel displays samples of firebrand collected under 3 m/s wind.

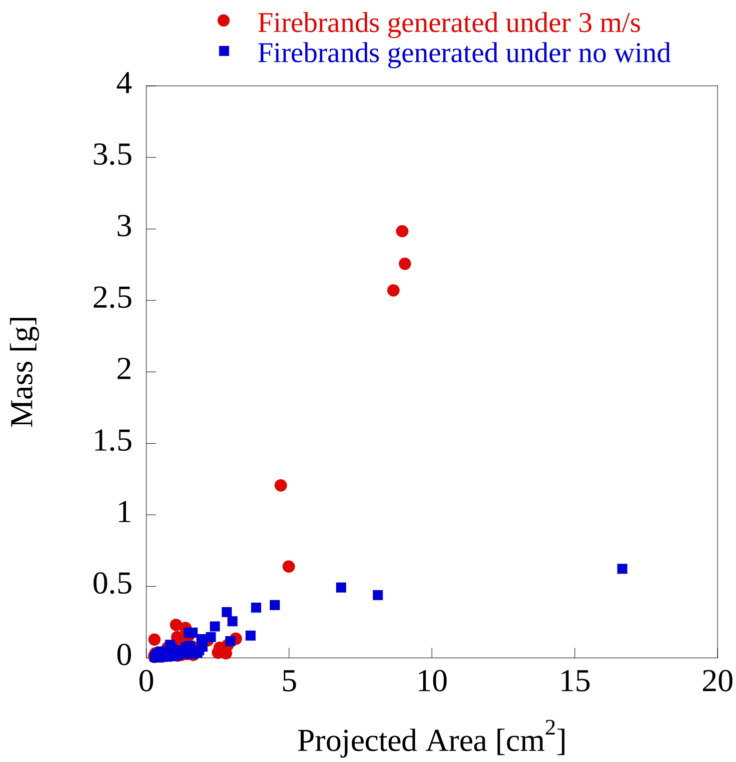

Figure 6 Mass and projected area of firebrands generated from the combustion of Noble-fir trees. Initial findings are presented for 3 m/s applied wind and compared to cases of no wind.

5. SUMMARY

In present study, Noble-fir trees were used to study the vegetative combustion process under an applied wind field. Noble-fir was used since it is easy to obtain from tree farms in the Western US and was easily imported to Japan. Two ignition methods were studied: the first employed a special propane burner and the second considered the use of firebrand showers impinging onto the trees. Some initial findings of associated firebrand production are presented under 3 m/s and compared to experiments performed under no wind conditions. This work presents an important step forward to understand vegetative combustion processes under wind.

6. REFERENCES

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